APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEM IN DATA ANALYSIS AND PRESENTATION FOR SEDIMENTATION STUDIES

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ABSTRACT

The relational capabilities of Geographical Information Systems (GIS) provide a very powerful analysis and visualization tool in a variety of ways. In the preparation of a sedimentation survey report, the U.S. Army Corps of Engineers (USACE) is determining sediment volumes deposited within a lake project over a given period of time. In addition to wanting to determine how much sediment is deposited, establishing a feel for where it is depositing and at what rate is critical. It is critical for purposes of determining potential impacts on flood control, water quality, water supply and recreation. The general procedure is to calculate sediment volumes to determine original and resurveyed capacities for the reservoir. Establishing a network of sediment ranges for the lake marked with monuments prior to completion of the dam and calculating resulting sediment accumulation based on these original ranges has historically been the USACE method of choice. We have seen many new technologies and surveying techniques emerge since the sediment range method was developed that will allow us to use more data in developing our model and give us a more detailed picture of the lake bed conditions. Through utilization of these new technologies Digital Terrain Model (DTM) methods using GIS to process contour and point data, we can create digital surfaces of the original and resurveyed lake bottom and perform the sedimentation calculations by comparing these two surfaces. In addition, utilization of GIS enables us to develop a visualization tool to more clearly understand impacts of the sedimentation.

Understanding the concepts, applying the tools and taking advantage of GIS capabilities can greatly reduce redundancy and increase efficiency in developing engineering products.

INTRODUCTION

Reservoirs maintained by the United States Army Corps of Engineers (USACE) offer many benefits to surrounding communities including flood control, water quality, water supply, fish and wildlife management and recreational activities. Determining the impacts of sediment on reservoir operation is critical to maintaining current operations and planning for future needs. The USACE routinely performs sedimentation surveys to determine the amount of sediment deposited over a given time period, and the distribution of sediment throughout the reservoir. The basic methodology for determining sediment volumes is to compare current reservoir capacity to the capacity before inundation. This paper will focus on the use of geographic information systems (GIS) to perform this analysis, and discuss the benefits of the digital terrain model (DTM) method over traditional methods of calculation.

TRADITIONAL APPROACH FOR SEDIMENTATION ANALYSIS (RANGE SURVEY / END AREA METHOD)

Traditional methods of analysis have relied on topographic mapping and range survey data to estimate sediment volumes for a reservoir. The site of the reservoir prior to inundation, referred to as original conditions, is marked on a topographic map and a planimeter is used to roll areas encompassed by individual contours. These areas are then used to determine incremental volumes for the lake below pool elevation, yielding the original capacity. The rate and distribution of sediment is then computed by comparing surveyed lake bottom profiles along a set of ranges established for the lake as depicted in Figure 1. Typically, the sediment range network is established and marked with monuments prior to dam construction. Pre-inundation profiles are surveyed and used to develop elevation-capacity relationships based on profile widths at prescribed elevation intervals. By resurveying the lake bottom along the ranges and comparing profile widths as shown in Figure 2, sediment volume and distribution are determined from the elevation-capacity relationships.

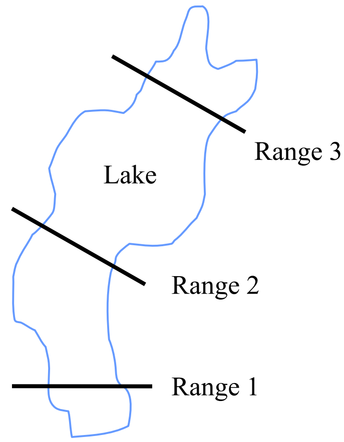

Figure 1. Sediment Range Network

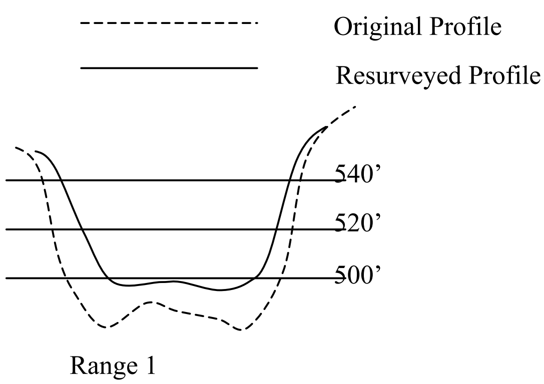

Figure 2. Original and resurveyed range profiles

The range survey / end area method has provided adequate results in past sedimentation analysis. However, ranges can be difficult to locate and survey as monuments are destroyed or worn away. This leads to the surveying of fewer ranges to characterize sedimentation. Also, while the method can accurately represent sediment volume and distribution, it lacks a visual component.

PROJECT ADVANCES

Technologies have emerged since the development of the range survey / end area method that allow data to be used in the development of lake bottom surface models, offering a detailed characterization of sediment distribution. The USACE has taken advantage of these technologies by incorporating GPS, sonar and GIS into a new method of sedimentation analysis, the DTM Method. This method was introduced with the year 2000 surveys, and has been used on 22 reservoirs to date within the Huntington District, including project sites in Kentucky, Ohio and West Virginia.

DIGITAL TERRAIN MODEL (DTM) METHOD

The application of the DTM Method to sedimentation analysis relies on the digital conversion of historical topographic mapping and the collection of recent sounding survey data to create digital surfaces of the lake bottom. The DTM method calculates sediment volumes over the entire lake area by comparing these digital surfaces. Through this comparison, sediment distribution can also be analyzed.

Original Conditions

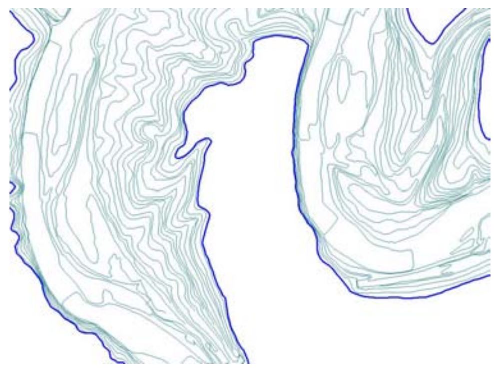

Figure 3. Digitized 5' contours and pool boundary

Topographic mapping of the site prior to inundation is used to represent original lake bottom conditions. These maps are digitized and registered in coordinate space to produce a contour coverage, typically in 5-foot intervals as shown in Figure 3. When necessary, information such as range survey data or USGS topographic mapping is used to supplement the contour coverage or for rectification. The bold line in Figure 3 represents the seasonal pool elevation for the lake, or the upper elevation limit for calculation purposes. This pool boundary, used to create a clipping polygon for the interpolation routine, and the contour data are processed in ArcInfo using the TOPOGRID command to produce a DTM that enforces a natural drainage pattern for the area as depicted in Figure 4. Once a quality digital surface has been produced and compared to the original contour mapping for accuracy, the elevation-capacity relationship is quickly determined by converting the lattice to a triangulated irregular network (TIN) and executing routines using the VOLUME command. Another routine is used to calculate horizontal capacities by dividing the DTM into ½ to 1-mile segments and computing volumes for each segment.

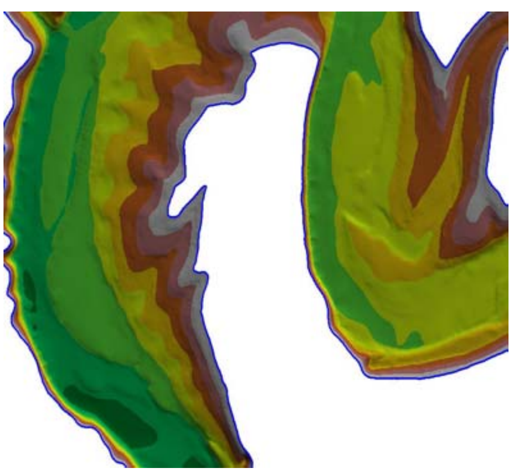

Figure 4. Original conditions DTM

Resurveyed Conditions

The resurveyed (or current) lake bed conditions are characterized by GPS/sonar point data collected from a boat traversing the water surface approximately perpendicular to the lake centerline. The boat is outfitted with a GPS unit linked to a fathometer. The GPS provides the x,y coordinate location of the survey point while the fathometer measures the depth. Depth is later converted to z elevation data based on the water surface elevation at the time of the survey.

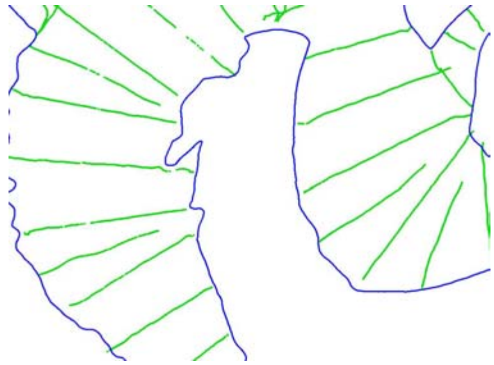

Figure 5. GPS / sonar point data collected in transects

Typically, survey data has been collected along transects as shown in Figure 5. Using transect data to generate surfaces may lead to anomalies or errors in the DTM between transects, depending on spacing. To reduce these errors, supplemental data points are interpolated and added between transects using routines developed in ArcView. These routines interpolate new points along lines (based on the channel trend) using inverse distance weighting as shown in Figure 6.

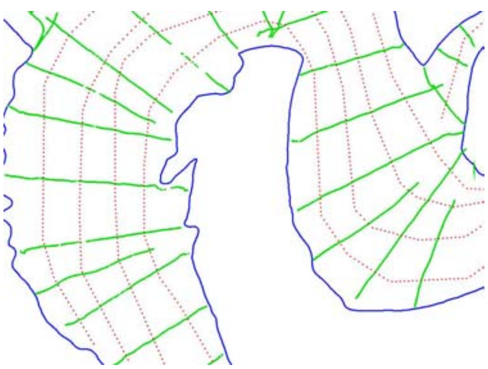

Figure 6. Interpolation of points to supplement transect data collection

Sedimentation calculations are limited to the lake bottom surface below seasonal pool. Therefore, a boundary representing the seasonal pool is needed to limit the interpolation routines and clip the data. However, lakes are often surveyed when water is below seasonal pool, and early studies lacked collection of an outer loop of points at water's edge. In these cases, the seasonal pool boundary from USGS topographic mapping is used to represent the pool elevation and generate the clipping polygon. More accurate resolution data sources will be used in lieu of the more coarse data sets when available.

To minimize the affect of transect surveys on DTM generation, it is recommended that subsequent sediment surveys collect sounding data in a random manner, yielding a 'scatter-shot' pattern as depicted in Figure 7. This will provide a uniform distribution of data points that produce a more accurate surface. In addition, it is recommended to survey the pool boundary during data collection. These recommendations have been incorporated into field surveys over the past three years, and

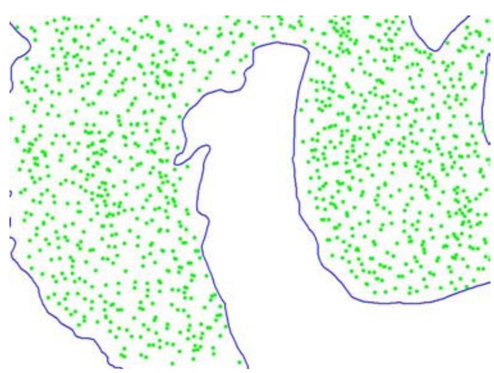

Figure 7. 'Scatter-shot' pattern of data points

recent studies have required far less pre-processing to create a quality DTM.

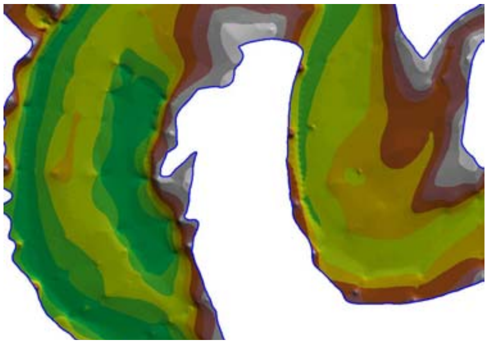

Figure 8. Resurveyed conditions DTM

The resurveyed DTM is created from the point data and pool boundary using TOPOGRID as shown in Figure 8, and cross sections are taken from the digital surface and compared to the raw point data for accuracy. The same interpolation routines used in the original conditions calculations are employed to yield the resurveyed capacities. Final calculations for the sediment volumes are determined by subtracting the original lake capacity from the resurveyed capacity.

VISUALIZATION PRODUCTS

The advantages of using the DTM method for sedimentation analysis become apparent with the creation of the water and sediment depth models. Water depths are calculated by subtracting the resurveyed DTM from the seasonal pool elevation. A lake bathymetry map can be created in this manner for any pool condition, offering valuable information for recreational activities and reservoir maintenance.

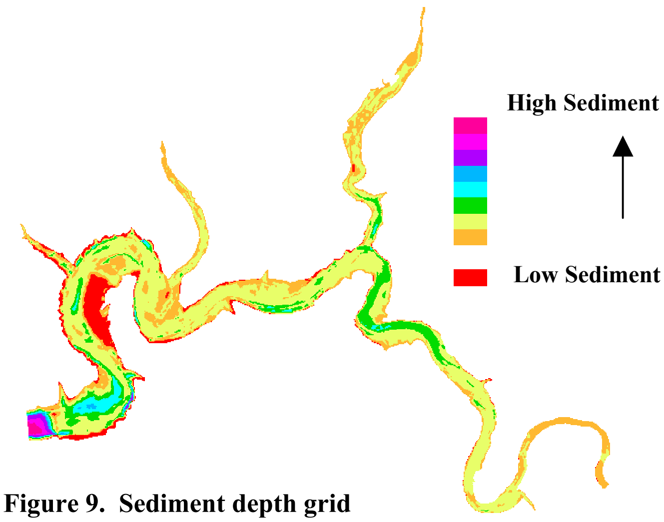

Figure 9. Sediment depth grid

Subtracting the original surface from the resurveyed surface creates a second visualization product, the sediment depth grid as depicted in Figure 9. The sediment depth grid provides a tool to visually evaluate sediment deposition. In addition, embankments and excavations that have occurred subsequent to the original lake bed survey, but prior to dam construction, can be evaluated and appropriate adjustments to the sediment analysis made.

BENEFITS OF A GIS BASED ANALYSIS

In addition to the visualization capabilities this method offers, GIS facilitates the integration of supporting data into the study. Once the mapping showing the axis of the dam is in true coordinate space, a contributing watershed boundary is delineated using custom ArcView routines and USGS Digital Elevation Models. Land use data is plotted to determine possible contributing factors to sedimentation and aerial photography can reveal recent development in the area.

A future benefit of this approach will be the ability to view time perspectives of sediment change. As additional surveys are performed for each reservoir, new sediment depth grids can quickly be created to represent sediment deposition since inundation, or with respect to prior surveys.

METHODS COMPARISON

Twelve of the twenty-two reservoirs that have been studied using the DTM method have had duplicate calculations performed using the range survey / end area method. Comparisons of original lake capacities have shown discrepancies of less than two percent, while resurveyed lake capacities have generally been within ten percent.

A key difference between the two methods is that the DTM method calculates sediment volumes over the entire lake area by comparing digital surfaces, whereas the traditional approach applies an average end area method to calculate volumes based on a limited number of ranges across the lake.

CONCLUSION

Both DTM and range survey / end area methods produce reasonable capacity and volume calculations in sedimentation analysis. The DTM method creates digital surfaces that accurately represent lake bottom conditions and support automated sedimentation calculations. Together with its visualization capabilities and the added spatial analysis inherent in a GIS, it is a more effective tool for performing sedimentation analysis than traditional methods.